SPECIFICATION

TITLE

"METHOD AND APPARATUS FOR ARTHRITIS DIAGNOSIS"

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention is directed to a method for determining the circumference of a digit joint (finger joint or toe joint,) in particular a proximal interphalangeal joint, to be evaluated in the context of an arthritis examination of an examination subject.

Description of the Prior Art

In the field of medicine, the task increasingly arises of being able to detect and evaluate pathological changes in tissue caused by metabolism in a simple manner that disturbs the patient as little as possible. An example of such pathological tissue changes is represented by rheumatic joint changes or rheumatic diseases in the area of the tissue. The finger joints, and above all the proximal interphalangeal joints, are particularly affected by such changes. Chronic arthritis often occurs as a symptom of aging, but also can be observed in younger people. The rheumatoid inflammation process of synovialis, i.e., an inflammation in the region of the joint, is associated with a swelling in the joint region. The stronger the degree of inflammation and thus of the rheumatic attack, the stronger is the swelling and thus the greater the circumference at the joint. This characteristic value describing the state of the joint is recorded in the context of an arthritis examination for diagnostic purposes, but the determination of the circumference is made manually by means of a flexible measuring strip that is placed around the joint. The measurement value is read from the measuring strip by the rheumatologist or by a medical technician, and is allocated to the respective finger joint and entered into the patient's database. The measurement precision is thereby at least

+/- 0.5 mm, but has proven to be larger in practice, which is related to the fact that the measuring strip can be drawn around or placed on the joint with varying strength, because the tissue and the skin are compressible. Reliable measurement values, which in particular could be used in the context of a running diagnosis, thus are not obtained.

SUMMARY OF THE INVENTION

An object of the present invention is to provide a method which allows the circumference of a digit joint, which represents an important characteristic value for the diagnosis of arthritis, to be measured with sufficient precision.

This object is achieved in accordance with the inventive method by irradiating the joint using a light source, and receiving at least one two-dimensional projection image using a camera apparatus, with the diameter of the joint in the projection image the being determined using an automatic edge detection method, and wherein the circumference is calculated on the basis of the joint diameter.

The inventive method enables a contact-free measurement of the circumference, which can be determined very precisely by means of the automatic edge detection method that is carried out at a computer. In an embodiment of the invention, the joint is irradiated, using a light source that is moved around the joint along a circular path, at various angular positions at a particular angular spacings. For each irradiation position the two-dimensional projection image is recorded using the camera apparatus. For each projection image the diameter (d_n) of the joint is determined using the automatic edge detection method and, on the basis of the diameter, the circumference is determined according to the formula

$$U = \sum_{n=1}^{n=x} d_n arc\Delta\varphi$$

where U = circumference

x = number of projection images

d_n = joint diameter in the respective projection image

$\Delta\varphi$ = angular difference between two angular positions.

In this embodiment of the method, the circumference is determined in contact-free fashion by recording a multiplicity of two-dimensional projection images of the joint illuminated from behind. Each recorded projection image, in which the joint is visible as a quasi-shadow, is evaluated using an automatic edge detection method, and the joint diameter in each projection is determined. In the context of the edge detection method, the diameter of the joint in the respective projection exposure should always be determined at the same location in relation to the longitudinal axis of the digit, so that it is ensured that the computer-calculated circumference is the circumference at a particular point of the joint. In the context of a running monitoring, it should be ensured that in subsequent determinations of circumference, the circumference is always determined at the same location. Edge detection methods are sufficiently known, with which it is possible to determine the transition between the skin and the air with the greatest precision. The projection images are recorded at various angular positions, the light source being moved about the joint along the circular path for this purpose. The determination of the circumference is made from the sum of the differential radian measures, according to the indicated equation. In this way, the circumference of the joint can be determined with particularly advantageously high precision. On the basis

of the change of the circumference over time, the degree of inflammation therefore can be diagnosed in a diagnostically effective manner. If the circumference increases, the degree of inflammation has increased, whereas if the joint swelling decreases, this indicates an improvement or a therapeutic success.

The projection images should be recorded over an angular distance of at least 180°, in order to ensure that the joint has been completely scanned. The angular difference $\Delta\varphi$ should be selected less than 5°, in particular less than 3°, and an angular difference of 2° is preferred. This ensures a sufficiently high number of recorded projection images. The higher the number, the more precisely the circumference can be determined. Given a step-by-step scanning with an angular difference of 2°, a total of 90 projection images are recorded, permitting a sufficiently precise determination.

The circumference, determinable with a high degree of precision by means of the inventive method, gives the diagnosing physician a characteristic value that is of excellent utility for the subsequent diagnosis and therapeutic monitoring.

In addition to a method for determining the characteristic value, the invention relates to a method for determining one or more information values of a digit joint, in particular of a proximal interphalangeal joint, of a subject that are relevant for a subsequent arthritis diagnosis,. This method combines the determination specified above of the circumference of the joint – forming a first characteristic value – with the execution of a diaphanoscopic examination of the joint, in which the joint is transilluminated with light having a wavelength in the region of the optical tissue window, and a scattered light distribution is recorded in the form of a spread function, after which one or more characteristic values, that are characteristic for the properties of the spread function ,are determined by computer based on the curve of the spread

function. Subsequently, the determined circumference and function characteristic values are combined with one another by computer, in order to determine one or more information emitted as outputs, on the basis of which the physician obtains important indications relating to the state of the joint that are useful for diagnosis and therapy. A diaphanoscopic examination method of this sort is specified in detail in WO 99/04683, corresponding to co-pending United States Application Serial No.09/463,110 filed January 19, 2000 ("Method for Evaluating a Distribution of Scattered Light, Obtained by Local Transirradiation of a living Organism by Determining Characteristic Values, Abraham-Fuchs et al.). The teachings of this co-pending United States application are incorporated herein by reference.

On the basis of the diaphanoscopic examination, a series of characteristic values that permit a description of the state of the tissue are provided to the physician. These characteristic values are determined from the scattered light distribution. For this purpose, the joint is transilluminated and, using a camera apparatus, the transmitted scattered light exiting at the opposite side is recorded and evaluated. The scattered light distribution is dependent on the state of the joint, which becomes worse as the inflammation process increases, with the result that the transmission characteristic becomes worse due to a cloudiness resulting from inflammation hypertrophy, resulting in a changing scattered light distribution. The results of this change can in turn be seen in the characteristic values that can be obtained. On the basis of these values, the rheumatologist obtains important information. According to the invention, in addition to this diaphanoscopic examination, the circumference also is determined, which likewise forms an important characteristic value, and, using a computer, the characteristic values obtained from the different methods and combined with one

another in order to determine the information values. A neural network model preferably is used for the computer-supported combination and in order to determine the information values. Alternatively to a neural network model, other networks, models or logics may of course also be used that enable the computer-aided combination and determination of information values. The information values based on the various characteristic values are even more important in their diagnostic content, and enable the physician to make a still better diagnosis.

In addition, the invention relates to an apparatus that is suitable for the execution of one or both of the above-described basic embodiments of the inventive methods. The apparatus includes a finger or toe support on which the finger or toe having the joint to be examined can be fixed, at least one light source with which the joint is irradiated, a camera apparatus for the recording of irradiation images, and a computer for processing and evaluation of the irradiation images supplied thereto.

In am embodiment of the inventive apparatus, the light source or sources and a camera apparatus located on the other side of the joint can be moved around the joint along a circular path.

The inventive apparatus is fashioned for the execution either the embodiment of the method for determining the circumference or for executing embodiment of the method requiring both a determination of circumference and a diaphanoscopic examination. The computer must merely be correspondingly designed – in the one case, for the calculation of the circumference, and in the other case additionally for the evaluation of the scattered light distributions. The two-dimensional projection images for determining the circumference, as well as the scattered light distributions, are recorded using the camera apparatus, which can be moved together with the light

source and which is arranged on the opposite side – i.e., the side facing away from the light source – of the finger or joint. For recording the two-dimensional projection images, a first light source for irradiation of the joint is used, preferably a flat light source, since the joint must be illuminated from the rear only so that the projection image can be recorded. For carrying out the diaphanoscopic examination, and thus for the recording of the scattered light distributions, it is preferable to use a second light source, preferably a laser light source, for punctiform irradiation of the joint. This light source is preferably arranged close to the first light source so as to be movable therewith, but it is also possible to arrange this second light source immovably, since a transillumination of the joint always takes place from the same side of the joint. In the simplest realization, the light source required in the context of the measurement of the circumference is stationary, as is the camera apparatus. Here a projection image is recorded in only one position, and the circumference is calculated on the basis of this one diameter. This very simple realization is possible in particular for home application, for rapid monitoring by the patient himself or herself. A diaphanoscopic examination is not absolutely required here.

According to a further embodiment of the invention, the camera apparatus can be arranged opposite the (first (and second)) light source. In this case, the light – regardless of whether a projection image or scattered light is being recorded – enters directly into the camera apparatus and is supplied to this apparatus to the computer, connected downstream. As an alternative, it is possible to employ a deflecting mirror, arranged opposite the light source and movable therewith. This mirror deflects the incident radiation by a 90° angle onto the camera apparatus arranged adjacent thereto, the camera apparatus also being moved with the light source and mirror. This specific

embodiment is advantageous in particular from a structural point of view, since in this way a hindrance of a rotational motion due to the camera apparatus, which is located relatively far away if positioned opposite, is avoided; this camera apparatus may otherwise collide with the adjacent fingers, and in such cases the required rotational motion is not always ensured.

The light source (or two light sources), arranged in the interior of an essentially hollow cylindrical mount, can be moved via a drive mechanism. The light source(s), the camera apparatus, and, if necessary, the deflecting mirror, are provided on the interior wall of the mount, which is open at one side and preferably closed at the opposite side. The mount is open at only one side in order to enable introduction of the digit, such as a finger. The darkness prevailing in the interior enables the recording of radiation images of sufficiently good quality, not adversely affected by parasitic radiation. The drive is preferably a stepper motor that, via a driven worm, engages a worm gear arranged on the mount. By means of this drive mechanism the mount can be rotated step-by-step into predetermined angular positions in which it is stopped and remains until advanced again. By this means, in a simple manner a step-by-step rotation of the mount and therefore of the recording components is enabled. The control of the mount drive mechanism should be designed so that the angular differences can be selected freely and the drive mechanism rotates the mount correspondingly.

During the motion of the mount around the joint, the first light source can emit light continuously, whereby at the camera apparatus images are recorded only at the selected angular positions. As an alternative, a pulsed operation of the light source, correlated with the stopping of the mount in the angular positions, can be employed. The recording of the projection images and of the scattered light distributions can take

place one after the other, or, alternatively, it is also possible to begin with the recording of the projection images and, when the angular position has been reached in which the scattered light distributions are recorded (as a rule, this is the position in which the second light source is located in perpendicular position under the joint), to record the scattered light distributions, after which the recording of the projection images is continued.

Since the inventive apparatus is intended to make it possible to be able to measure the finger or toe joints of all fingers/toes of a living subject, care must be taken that, given digits of different lengths, the joint to be examined can always be brought into the image recording region. For this purpose, according to the invention the finger or toe support housed in the interior of the mount can be moved in the direction of its longitudinal axis, a stepper motor likewise preferably being used for this purpose. This version of the invention makes it possible to fix an arbitrary finger of a hand on the finger or toe support, and subsequently to position it precisely. The use of a movable support additionally has the advantage that it is possible to work with a single laser light source in the context of the carrying out of the diaphanoscopic examination. In the context of this examination, as is specified in detail in United States Application Serial No. 09/463,110, the joint is irradiated with the laser light at a multiplicity of locations disposed in a direction perpendicular to the joint gap, i.e., a number of scattered light distributions are recorded and subsequently evaluated. The possibility of moving the finger or toe support makes it possible to move this support past the laser light source, which may be a laser diode, in step-by-step fashion, and thus to move the joint past the laser light source in order to scan it.

A further advantage of this embodiment is that the optimal locus of radiation for the diaphanoscopic examination can be found in an equally simple manner. The above-cited number of irradiation points are placed around an optimal locus of radiation. The determination of the optimal locus of radiation takes place according to the method as specified in application Serial No. 09/463,110. In order to find this locus, it is also required that the joint be transilluminated at a number of points. If the support can be moved, the joint can also be moved past the stationary laser light source for this purpose.

A common control unit for controlling the operation of the light source(s) and for the movement of the mount, as well as the movement of the finger or toe support, is preferably provided.

DESCRIPTION OF THE DRAWINGS

Figure 1 is a schematic illustration of an inventive apparatus.

Figure 2 is a schematic illustration for the representation of a cross-section of a finger joint for explaining the calculation of the circumference.

Figure 3 is a side view of a calibration bar for calibrating the apparatus according to Figure 1.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Figure 1 shows, in the form of a schematic drawing, an inventive apparatus 1 for carrying out both versions of the inventive method in the context of a finger examination. The invention, however, can also be used to conduct the same examination for a toe. The apparatus 1 has a finger support 2, on which a finger 3 whose joint 4 (a proximal interphalangeal joint) is to be examined can be fastened using fixing means not shown in more detail. The support 2, shown in a partial section, has

a finger trough 5 in which the finger rests. The fingertip is held in a recess 6 that prevents the finger from being lifted accidentally. The finger support 2 can be moved back and forth in the direction of the double arrow A via a drive mechanism 7, in order to move and adjust the joint 4 in relation to light sources 8, 9. The light sources 8, 9 are used for irradiation of the joint 4. In order to enable this, an opening 10 is provided on the finger support 2, irradiation taking place through this recess. The opening is, for example, 30 mm long.

The finger support 2 protrudes into a hollow cylindrical mount 11, which has an entry opening 12 on its front side and has a closing wall 13 on its back side. In this way it is ensured that it is sufficiently dark in the interior of the mount 11 so that the radiation images to be exposed will not be falsified by incident light.

The two light sources 8, 9 are arranged on the inner wall of the mount 11. On the opposite wall there is arranged a deflecting mirror 14, by means of which incident radiation from the finger joint 4 is deflected onto a camera apparatus 15, which is a miniature camera module having a CCD sensor 16 (see arrows B). The CCD sensor 16 can have a resolution of 640 x 480 pixels (= 350,000 pixels). Due to its integration in the interior of the mount 11, the camera apparatus 15 itself should be as small as possible, so that the apparatus as a whole can be designed to be small. The image signals read out by the CCD sensor 16 are given, via a line connection 17, to a computer 18, to which a display 19 in the form of monitor is connected downstream.

The light sources 8, 9, the deflecting mirror 14, and the camera apparatus 15 are fixed on the inner wall of the mount 11. The mount 11 itself can be moved around the axis of rotation X via a worm gear 20 (this can also be a toothed wheel or the like) and a stepper motor 21 that engages this gear 20 (see arrow C). If the mount 11 is rotated,

the light sources 8, 9, the deflecting mirror 14, and the camera apparatus 15 are moved around the finger joint 4. In this way, it is possible to irradiate the finger joint 4 with light from the first light source 8, which is a flat light source, from a number of positions, and to record different projection images using the camera apparatus 15. The operation of the light sources 8, 9 and of the stepper motors 7 and 21 is controlled via a central control unit 22.

Using the inventive apparatus, two-dimensional projection image exposures of the joint 4 are possible. For this purpose, the mount is moved into an initial position, for example the position shown in Figure 1, in which the light source 8 is located in perpendicular position under the joint 4. Using the stepper motor 21, the mount 11 is now rotated step-by-step through 180°. At angular positions respectively spaced 2° from one another, a projection image exposure is respectively recorded using the camera apparatus 15. For this purpose, the light source 8 is switched on in this position, or, as an alternative, it can also be operated during the entire 180° rotation. The geometrical two-dimensional projection of the joint 4 is deflected via the deflecting mirror 14 onto the camera apparatus 15, which records the image in the CCD sensor 16. This image is subsequently read out into the computer 18. Given an angular difference between the recording positions of $\Delta\varphi = 2°$, with a rotation scan of $\varphi = 180°$ a total of 90 projection images result, in each of which the finger joint is shown in a slightly different position.

Using an edge detection method, the computer 18 is now able to determine the diameter of the finger joint shown in each projection, so that overall, given a number x of projection images, a corresponding number of diameters d_n is obtained, which are respectively allocated to different angular positions. On the basis of these determined

diameter values, the computer 18 can now acquire the precise circumference of the finger joint 4 on the basis of the equation

$$U = \sum_{n=1}^{n=x} d_n arc\Delta\varphi$$

On the basis of two diameters d_1 and d_2, Figure 2 illustrates how the diameter changes as the recording position changes, and how the above equation results. The circumference of the finger joint 4 increases as the degree of inflammation advances. Because the apparatus 1 determines the diameter without contact, a high precision is possible in the determination of the circumference, and comparable values can be recorded in the context of running tests in order to observe the development of the inflammation. The circumference is a useful characteristic value for the rheumatologist's diagnosis.

Besides this embodiment for determining circumference, using the apparatus 1 a number of scattered light distributions also can be recorded and evaluated, in order to determine further characteristic values that are important for the subsequent diagnosis. In the context of the diaphanoscopic examination, the finger joint is transilluminated with light from the light source 9. In the depicted exemplary embodiment, this is a single laser diode that emits narrowband light having a wavelength in the region of the optical tissue window. This light penetrates the joint 4, which is transparent in the region of the joint gap as well as in the cartilage region and in the region of the joint fluid, and exits at the opposite side of the joint 4 as scattered light. This scattered light is deflected via the deflecting mirror 14 into the camera apparatus 15, where the scattered light distribution is recorded and is subsequently

read out to the computer 18. In order to carry out this diaphanoscopic examination, the finger joint 4 first must be positioned over the light source 9 in such a way that the optimal locus of radiation at the joint 4 is located precisely over the light source 9. In order to determine the optimal locus of radiation, the region of the joint 4 in which the optimal examination locus is probably located is first positioned roughly over the light source 9, and subsequently transilluminations are made sequentially at various points located next to one another, in order to record first scattered light distributions in the form of locus-related spread functions, in particular point spread functions, which are subsequently evaluated at the computer 18. The precise procedure for the determination of this optimal locus of examination is specified in application Serial No. 09/463,110. For the sequential illumination, the finger support 2 is displaced in step-by-step fashion in relation to the light source 9, which takes place by means of the stepper motor 7.

Once the optimal locus of examination has been determined by the computer 18, the finger support 2 is positioned correspondingly, so that this optimal locus of examination is located precisely over the light source 9. The computer 18 forwards the corresponding information to the control units 22, which correspondingly controls the stepper motor 7. It should be noted that this control unit 22 can of course be integrated into the computer 18, that is, the computer means 18 directly controls the aforementioned components.

After successful positioning, the actual diaphanoscopic examination takes place, in the course of which a number of scattered light distribution images are recorded at various positions around the optimal locus of examination. For this purpose, the finger support 2 is again displaced in step-by-step fashion, the individual loci of radiation

being, for example, respectively spaced 200 μm from one another, symmetrical to the center of the joint gap. At each location, the light source 9 is operated briefly in order to record the scattered light distribution. The individual scattered light distributions are evaluated at the computing unit 18 for the determination of one or more distribution-related characteristic values. An evaluation method is specified in application Serial No. 09/463,110.

It is possible to display the individual characteristic values themselves to the physician on the display 19. It is useful, however, to combine the characteristic values resulting from the determination of circumference and the scattered light distribution analysis with one another, because, due to their dependence on the degree of inflammation, they all contain information describing this degree of inflammation indirectly. If these characteristic values describing the state of the joint are combined with one another, information values that are still more effective for diagnostic purposes can be determined. For this purpose, the characteristic values are processed at the computer 18 in a neural network.

Figure 3 shows a calibration bar 23 that is non-reflecting and that has in its middle region a thickening in the shape of a truncated cone that is for example 20 mm in diameter. For calibration purposes, this thickening is moved into the illumination region and the calibration measurements are carried out.

Although modifications and changes may be suggested by those skilled in the art, it is the intention of the inventors to embody within the patent warranted hereon all changes and modifications as reasonably and properly come within the scope of their contribution to the art.